

Conventional Numerical Control

1-Numerical control defined

Numerical control can be defined as a form of programmable automation in which the process is controlled by numbers, letters, and symbols. In NC, the numbers form a program of instructions designed for a particular workpart or job. When the job is changes, the program of instructions is changed. This capability to change the program for each new job is what gives NC its flexibility. It is much easier to write new programs than to make major changes in the production equipment.

NC technology has been applied to a wide variety of operation, including drafting, assembly, inspection, sheet metal press-working, and spot welding. However, numerical control finds its principal applications in metal machining processes. The machined workparts are designed in various sizes and shapes, and most machined parts produced in industry today are made in small to medium-size batches. To produce each part, a sequence of drilling operations may be required, or a series of turning or milling operations. The suitability of NC for these kinds of jobs is the reason for the tremendous growth of numerical control in the metalworking industry over the last 25 years.

2-BASIC COMPONENTS OF AN NC SYSTEM

An operational numerical control system consists of the following three basic components:

2-1 Program of instructions

2-2 Controller unit, also called a machine control unit (MCU)

2-3 Machine tools or other controlled process

The general relationship among the three components is illustrated in Figure (1). The program of instructions serves as the input to the controller unit, which in turn commands the machine tool or other process to be controlled. We will discuss the three components in the sections below.

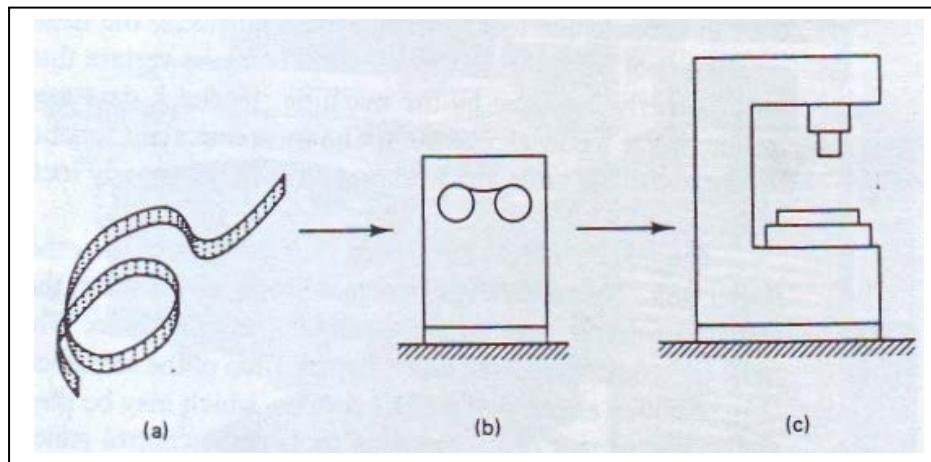


Fig (1): three basic components of a numerical control system: (a) program of instruction; (b) controller unit; (c) machine tool

2-1 Program of instructions: -

The program of instructions is the detailed step-by-step set of directions which tell the machine tool what to do. It is coded in numerical or symbolic form on some type of input medium that can be interpreted by the controller unit. The most common input medium today is 1-in.-wide punched tape. Over the years, other forms of input media have been used, including punched cards, magnetic tape, and even 35-mm motion picture film.

There are two other methods of input to the NC system which should be mentioned. The first is by manual entry of instructional data to the controller unit. This method is called manual data input, abbreviated MDI, and is appropriate only for relatively simple jobs where the order will not be repeated. We will discuss MDI more thoroughly later. The second other method of input is by means of a direct link with a computer. This is called direct numerical control, or DNC. We discuss DNC later.

The program of instructions is prepared by someone called a part programmer. The programmer's job is to provide a set of detailed instructions by which the sequence of processing steps is to be performed. For a machining operation, the processing steps involve the relative movement between the cutting tool and the workpiece.

2-2 Controller unit also called a machine control unit (MCU): -

The second basic component of the NC system is the controller unit. This consists of the electronics and hardware that read and interpret the program of instructions and convert it into mechanical actions of the machine tool. The typical elements of a conventional NC controller unit include the tape reader, a data buffer, signal output channels to the machine tool, feedback channels from the machine tool, and the sequence controls to coordinate the overall operation of the foregoing elements. It should be noted that nearly all modern NC systems today are sold with a microcomputer as the controller unit. This type of NC is called computer numerical control (CNC). We discuss CNC later.

The tape reader is an electromechanical device for winding and reading the punched tape containing the program of instructions. The data contained on the tape are read into the data buffer. The purpose of this device is to store the input instructions in logical blocks of information. A block of information usually represents one complete step in the sequence of processing elements.

The signal output channels are connected to the servomotors and other controls in the machine tool. Through these channels, the instructions are sent to the machine tool from the controller unit. To make certain that the instructions have been properly executed by the machine, feedback data are sent back to the controller via the feedback channels. The most important function of this return loop is to assure that the table and workpart have been properly located with respect to the tool.

Sequence controls coordinate the activities of the other elements of the controller unit. The tape reader is actuated to read data into the buffer from the tape. Signals are sent to and from the machine tool, and so on. These types of operations must be synchronized and this is the function of the sequence controls.

Another element of the NC system, which may be physically part of the controller unit or part of the machine tool, is the control panel. The control panel or control console contains the dials and switches by which the machine operator runs the NC system. It may also contain data displays to provide information to the operator. Although the NC system is an automatic system, the human operator is still needed to turn the machine on and off, to change tools (some NC systems have automatic tool changers), to load and unload the machine, and to perform various other duties.

2-3 Machine tools or other controlled process: -

The third basic component of an NC system is the machine tool or other controlled process. It is the part of the NC system which performs useful work. In the most common example of an NC system, one designed to perform machining operations, the machine tool consists of the work table and spindle as well as the motors and controls necessary to drive them. It also includes the cutting tools. Work fixtures, and other auxiliary equipment needed in the machining operation. Figure (2) illustrates an NC machine tool.

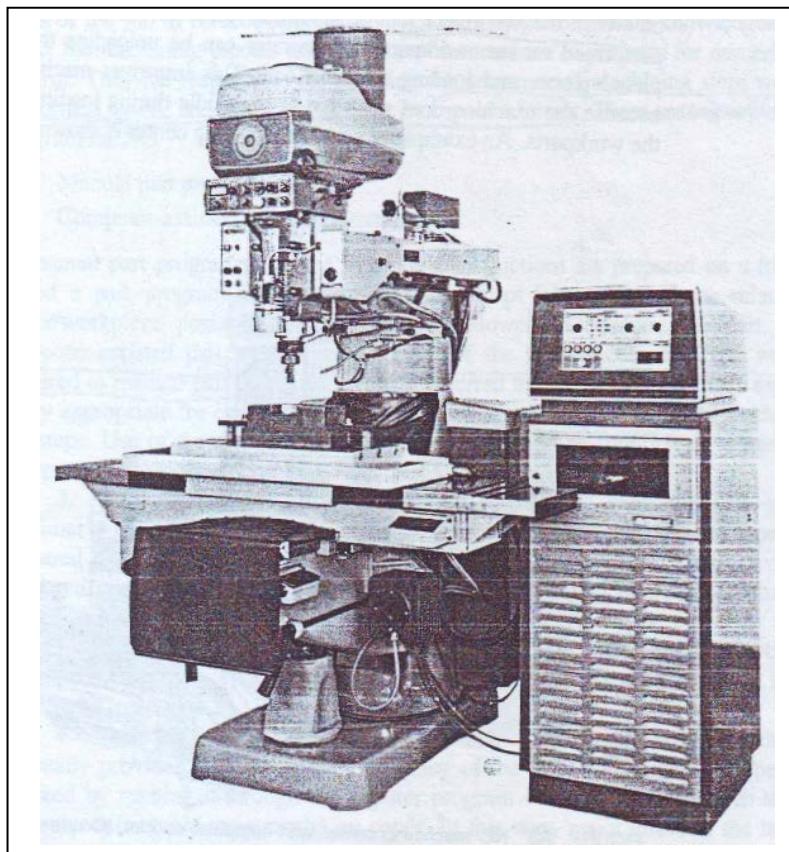


Fig (2): NC system showing machine tool and controller

The NC machining center was fast introduced in the late 1950s. It is a multifunction machine which incorporates several timesaving features into a single piece of automated production equipment. First, a machining center is capable of performing variety of different operations: drilling, tapping, reaming, milling, and boring. Second; it has the capacity to change tools automatically under tape command. A third capability of the NC machining center is workpiece positioning. The machine table can orient the job so that it can be machine on several surfaces, as required.

Finally; fourth feature possessed by some machining centers is the presence of two tables or pallets on which the workpiece can be fixtured. An example of an NC machining center is shown in Figure (3).

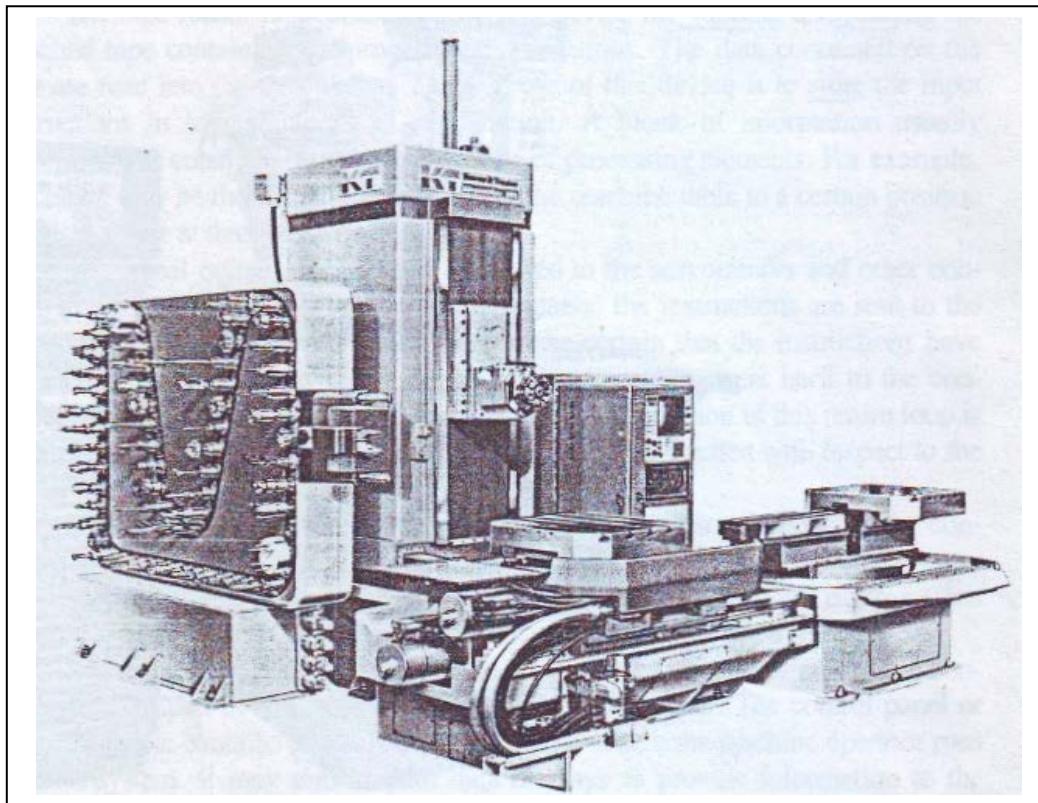


Fig (3): NC machining center with computer control

3-The NC Procedure

To utilize numerical control in manufacturing, the following steps must be accomplished.

1-Process planning: - The engineering drawing of the workpart must be interpreted in terms of the manufacturing processes to be used. This step is referred to as process planning and it is concerned with the preparation of a route sheet. The route sheet is a listing of the sequence of operations which must be performed on the workpart. It is called a route sheet because it also lists the machines through which the part must be routed in order to accomplish the sequence of operations.

2-Part programming: - A part programmer plans the process for the portions of the job to be accomplished by NC. Part programmers are knowledgeable about the machining

process and they have been trained to program for numerical control. They are responsible for planning the sequence of machining steps to be performed by NC and to document these in a special format. There are two ways to program for NC:

- ◆ Manual part programming: - In manual part programming, the machining instructions are prepared on a form called a part program manuscript. The manuscript is a listing of the relative cutter/workpiece positions which must be followed to machine the part.
- ◆ Computer-assisted part programming: - In computer-assisted part programming, much of the tedious computational work required in manual part programming is transferred to the computer. This is especially appropriate for complex workpiece geometries and jobs with many machining steps. Use of the computer in these situations results in significant savings in part programming time.

3- Tape preparation: - A punched tape is prepared from the part programmer's NC process plan. In manual part programming, the punched tape is prepared directly from the part program manuscript on a typewriter like device equipped with tape punching capability. In computer-assisted part programming, the computer interprets the list of part programming instructions, performs the necessary calculations to convert this into a detailed set of machine tool motion commands, and then controls a tape punch device to prepare the tape for the specific NC machine.

4- Tape verification: - After the punched tape has been prepared, a method is usually provided for checking the accuracy of the tape. Sometimes the tape is checked by running it through a computer program which plots the various tool movements (or table movements) on paper. In this way, major errors in the tape can be discovered. The "acid test" of the tape involves trying it out on the machine tool to make the part. A foam or plastic material is sometimes used for this tryout.

5- Production: - The final step in the NC procedure is to use the NC tape in production. This involves ordering the raw workparts, specifying and preparing the tooling and any special fixturing that may be required, and setting up the NC machine tool for the job. The machine tool operator's function during production is to load the raw workpart in the machine and establish the starting position of the cutting tool relative to the workpiece. The NC system then takes over and machines the part according to the

instructions on tape. When the part is completed, the operator removes it from the machine and loads the next part.

4-NC Coordinate System

In order for the part programmer to plan the sequence of positions and movements of the cutting tool relative to the work-piece, it is necessary to establish a standard axis system by which the relative positions can be specified. Using an NC drill press as an example, the drill spindle is in a fixed vertical position, and the table is moved and controlled relative to the spindle. However, to make things easier for the programmer, we adopt the viewpoint that the workpiece is stationary while the drill bit is moved relative to it. Accordingly, the coordinate system of axes is established with respect to the machine table.

Two axes, x and y , are defined in the plane of the table, as shown in Figure (4). The z axis is perpendicular to this plane and movement in the z direction is controlled by the vertical motion of the spindle. The positive and negative directions of motion of tool relative to table along these axes are as shown in Figure (4). NC drill presses are classified as either two-axis or three-axis machines, depending on whether or not they have the capability to control the z axis.

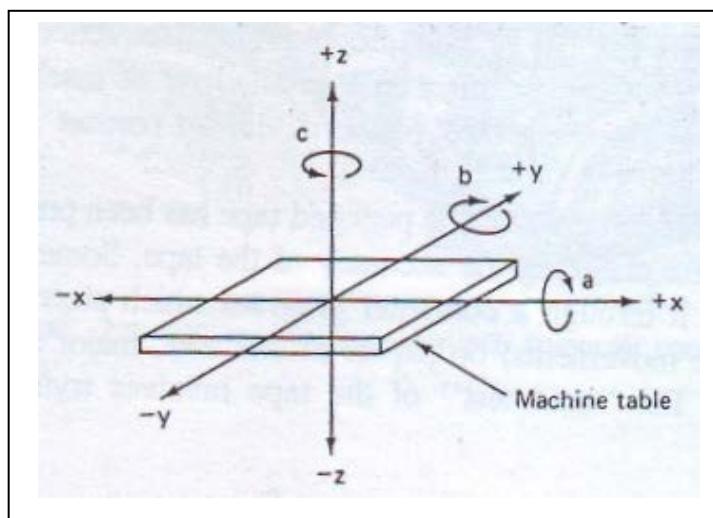


Fig (4): NC machine tool axis system for milling and drilling operation

In addition to the three linear axes, these machines may possess the capacity to control one or more rotational axes. Three rotational axes are defined in NC; the a , b , and c axes. These axes specify angles about the x , y , and z axes, respectively. To

distinguish positive from negative angular motions, the "right-hand rule" can be used. Using the right hand with the thumb pointing in the positive linear axis direction (z , y , or z), the fingers of the hand are curled to point in the positive rotational direction.

For turning operations, two axes are normally all that are required to command the movement of the tool relative to the rotating workpiece. The z -axis is the axis of rotation of the workpart, and x -axis defines the radial location of the cutting tool. This arrangement is illustrated in Figure (5). The purpose of the coordinate system is to provide a means of locating the tool in relation to the workpiece. Depending on the NC machine, the programmer may have several different options available for specifying this location.

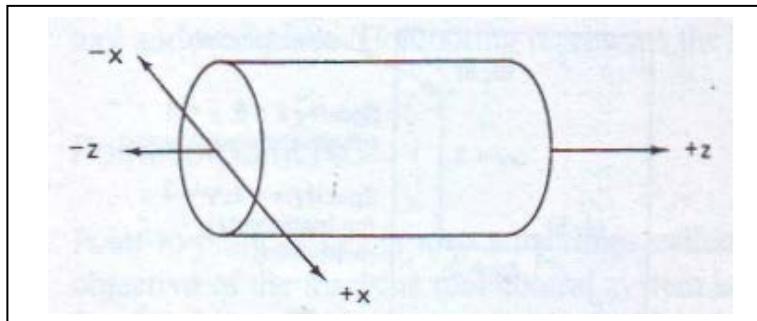


Fig (5): NC machine tool axis system for turning operation

❖ Fixed zero and floating zero: -The programmer must determine the position of the tool relative to the origin (zero point) of the coordinate system. NC machines have either of two methods for specifying the zero point. The first possibility is for the machine to have a fixed zero. In this case, the origin is always located at the same position on the machine table. Usually, that position is the southwest corner (lower left-hand corner) of the table and all tool locations will be defined by positive x and y coordinates.

The second and more common feature on modern NC machines allows the machine operator to set the zero point at any position on the machine table. This feature is called floating zero. The part programmer is the one who decides where the zero point should be located. The decision is based on part programming convenience. For example, the workpart may be symmetrical and the zero point should be established at the center of symmetry. The location of the zero point is communicated to the machine operator. At the beginning of the job, the operator moves the tool under manual control to some "target point" on the table. The target point is some convenient place on the

workpiece or table for the operator to position the tool. For example, it might be a predrilled hole in the workpiece. The target point has been referenced to the zero point by the part programmer. In fact, the programmer may have selected the target point as the zero point for tool positioning. When the tool has been positioned at the target point, the machine operator presses a “zero” button on the machine tool, which tells the machine where the origin is located for subsequent tool movement.

◆ Absolute positioning and incremental positioning: - Another option sometimes available to the part programmer is to use either an absolute system of tool positioning or an incremental system. Absolute positioning means that the tool locations are always defined in relation to the zero point. If a hole is to be drilled at a spot that is 8 in. above the x axis and 6 in. to the right of the y-axis, the coordinate location of the hole would be specified as $x = +6.000$ and $y = +8.000$. By contrast, incremental positioning means that the next tool location must be defined with reference to the previous tool location. If in our drilling example, suppose that the previous hole had been drilled at an absolute position of $x = +4.000$ and $y = +5.000$. Accordingly, the incremental position instructions would be specified as $x = +2.000$ and $y = +3.000$ in order to move the drill to the desired spot. Figure (6) illustrates the difference between absolute and incremental positioning.

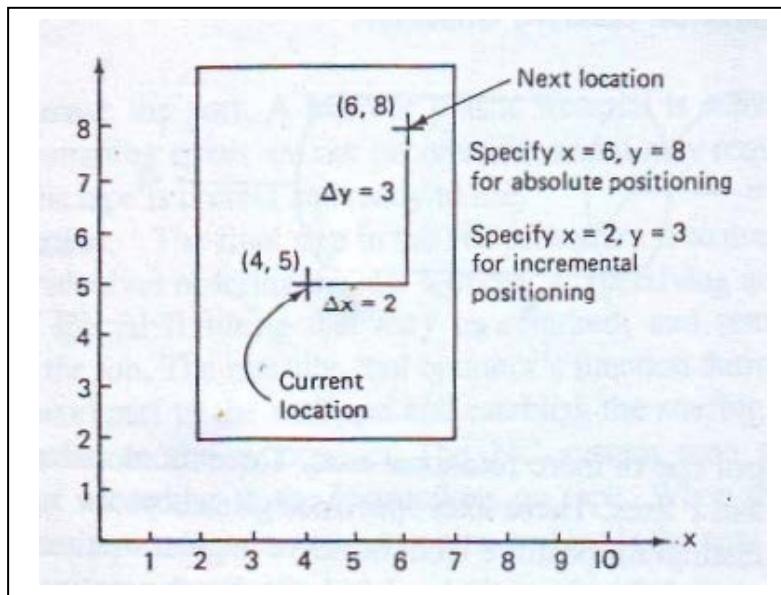


Fig (6): Absolute versus incremental positioning

5-Application of Numerical Control

Numerical control systems are widely used in industry today, especially in the metalworking industry. By far the most common application of NC is for metal cutting machine tools. Within this category, numerically controlled equipment has been built to perform virtually the entire range of material removal processes, including (milling, drilling and related processes, boring, turning, grinding and sawing).

Within the machining category, NC machine tools are appropriate for certain jobs and inappropriate for others. Following are the general characteristics of production jobs in metal machining for which numerical control would be most appropriate:

- 1- Parts are processed frequently and in small lot sizes.
- 2-The part geometry is complex.
- 3-Many operations must be performed on the part in its processing.
- 4-Much metal needs to be removed.
- 5-Engineering design changes are likely.
- 6-Close tolerances must be held on the workpart.
- 7-It is an expensive part where mistakes in processing would be costly.
- 8-The parts require 100% inspection.

In addition to metal machining, numerical control has been applied to a variety of other operations. The following, will give the reader an idea of the wide range of potential application of NC (Pressworking machine tool, welding machines, inspection machines, automatic drafting, assembly machines, tube bending, flame cutting, plasma arc cutting, laser beam process, automated knitting machines, cloth cutting, automatic riveting and wire-wrap machines).

6-Advantage of NC

- 1- Reduced nonproductive time: - Numerical control has little or no effect on the basic metal cutting (or other manufacturing) process. However, NC can increase the proportion of time the machine is engaged in the actual process. It accomplishes this by

means of fewer setups, less time in setting up, reduced workpiece handling time, automatic tool changes on some machines, and so on.

2- Reduced fixturing: - NC requires fixtures which are simpler and less costly to fabricate because the positioning is done by the NC tape rather than the jig or fixture.

3- Reduced manufacturing lead time: - Because jobs can be set up more quickly with NC and fewer setups are generally required with NC, the lead time to deliver a job to the customer is reduced.

4- Greater manufacturing flexibility: - With numerical control it is less difficult to adapt to engineering design changes, alterations of the production schedule, changeovers in jobs for rush orders, and so on.

5- Improved quality control: - NC is ideal for complicated workparts where the chances of human mistakes are high. Numerical control produces parts with greater accuracy, reduced scrap, and lower inspection requirements.

6- Reduced inventory: - Owing to fewer setups and shorter lead times with numerical control, the amount of inventory carried by the company is reduced.

7-Reduced floor space requirements: - Since one NC machining center can often accomplish the production of several conventional machines, the amount of floor space required in an NC shop is usually less than in a conventional shop.

7-Disadvantage of NC

1- Higher investment cost: - Numerical control machine tools represent a more sophisticated and complex technology. This technology costs more to buy than its non-NC counterpart. The higher cost requires manufacturing management's to use these machines more aggressively than ordinary equipment. High machine utilization is essential in order to get reasonable returns on investment. Machine shops must operate their NC machines two or three shifts per day to achieve this high machine utilization.

2- Higher maintenance cost: - Because NC is a more complex technology and because NC machines are used harder, the maintenance problem becomes more acute. Although the reliability of NC systems has been improved over the years, maintenance costs for NC machines will generally be higher than for conventional machine tools.

3- Finding and/or training NC personnel: - Certain aspects of numerical control shop operations require a higher skill level than conventional operations. Part programmers and NC maintenance personnel are two skill areas where available personnel are in short supply. The problems of finding, hiring, and training these people must be considered a disadvantage to the NC shop.